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Linzer

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(54) **PICTURE BRIGHTNESS ADJUSTED TEMPORAL FILTERING**

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(22) Filed: **Jun. 29, 2015**

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G06T 5/00	(2006.01)
G06T 5/10	(2006.01)

(52) **U.S. Cl.**
CPC . ***G06T 5/10*** (2013.01); ***G06T 5/007*** (2013.01); *G06T 2207/10004* (2013.01); *G06T 2207/20024* (2013.01)

(58) **Field of Classification Search**
CPC G06T 5/001; G06T 5/20; G06T 5/50; G06T 2207/20012; G06K 9/40; H04N 7/50; H04N 7/26244; H04N 7/361; H04N 7/26765; H04N 7/26271
See application file for complete search history.

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* cited by examiner

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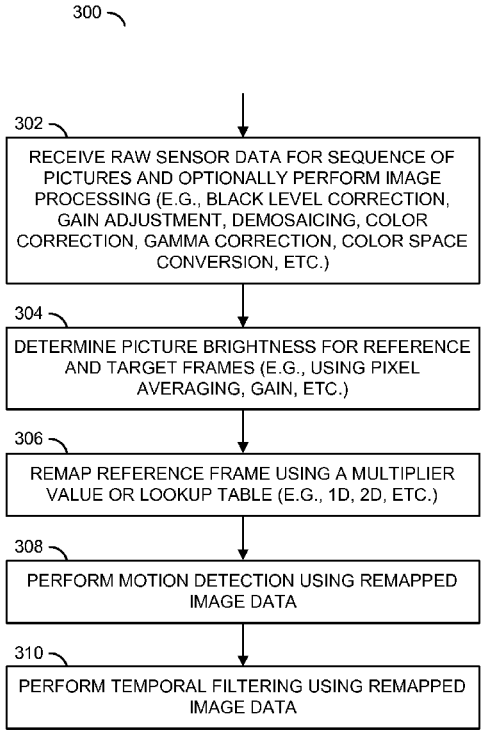
(57) **ABSTRACT**

An apparatus includes an input circuit configured to receive a sequence of pictures and a processing circuit. The processing circuit may be configured to (i) determine respective picture brightness values for each of a reference picture and a target picture selected from the sequence of pictures, (ii) remap image data of the reference picture based upon the respective picture brightness values, and (iii) perform temporal filtering between the reference picture and the target picture utilizing the remapped image data.

20 Claims, 9 Drawing Sheets



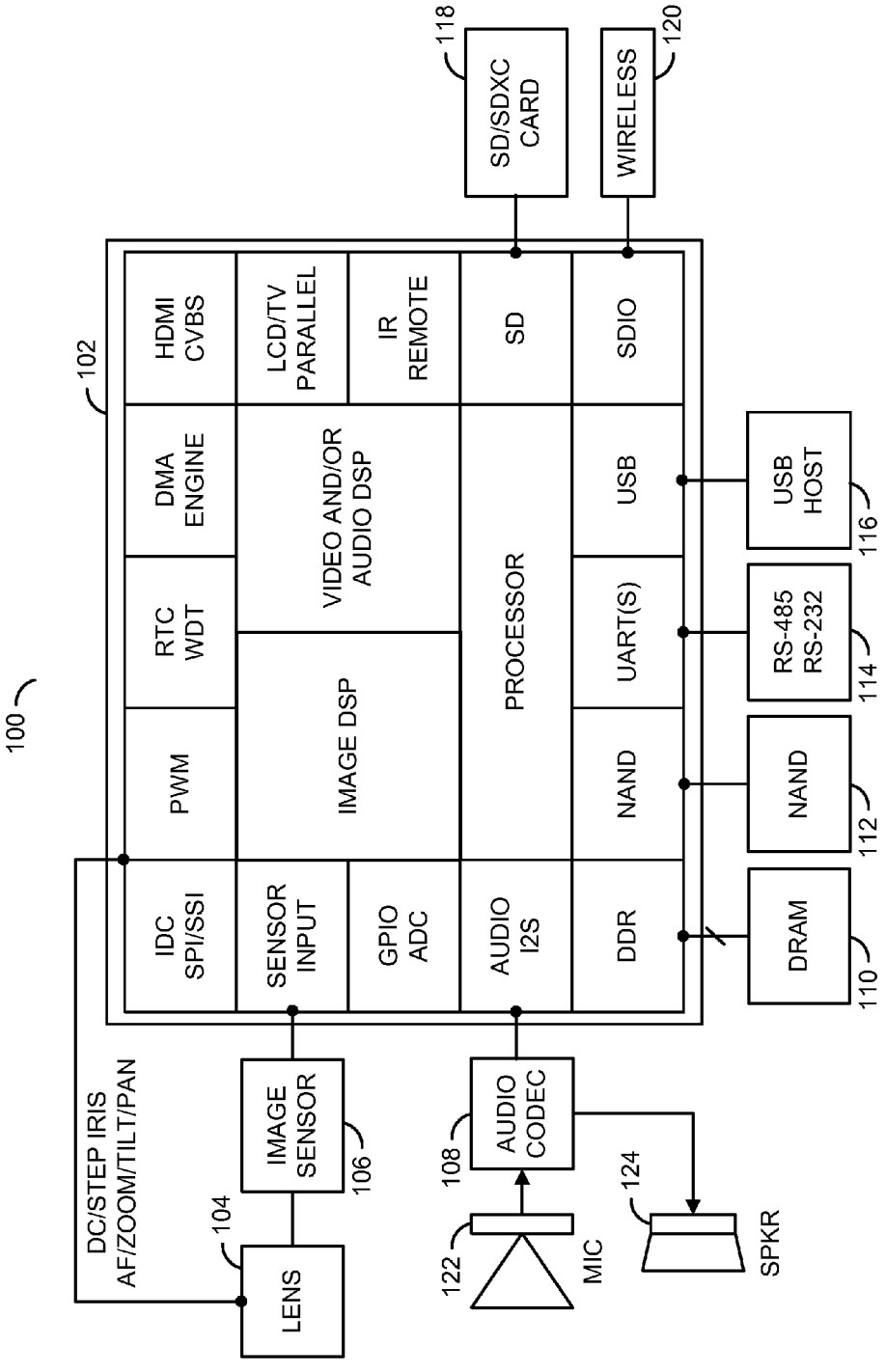

100
102
IDC SPI/SSI
PWM
RTC WDT
DMA ENGINE
HDMI CVBS
SENSOR INPUT
IMAGE DSP
VIDEO AND/OR AUDIO DSP
LCD/TV PARALLEL
GPIO ADC
IR REMOTE
AUDIO I2S
PROCESSOR
SD
DDR
NAND
UART(S)
USB
SDIO
DRAM
NAND
RS-485 RS-232
USB HOST
110
112
114
116
118
SD/SDXC CARD
120
WIRELESS
DC/STEP IRIS AF/ZOOM/TILT/PAN
LENS
104
IMAGE SENSOR
106
AUDIO CODEC
108
MIC
122
SPKR
124

FIG. 1

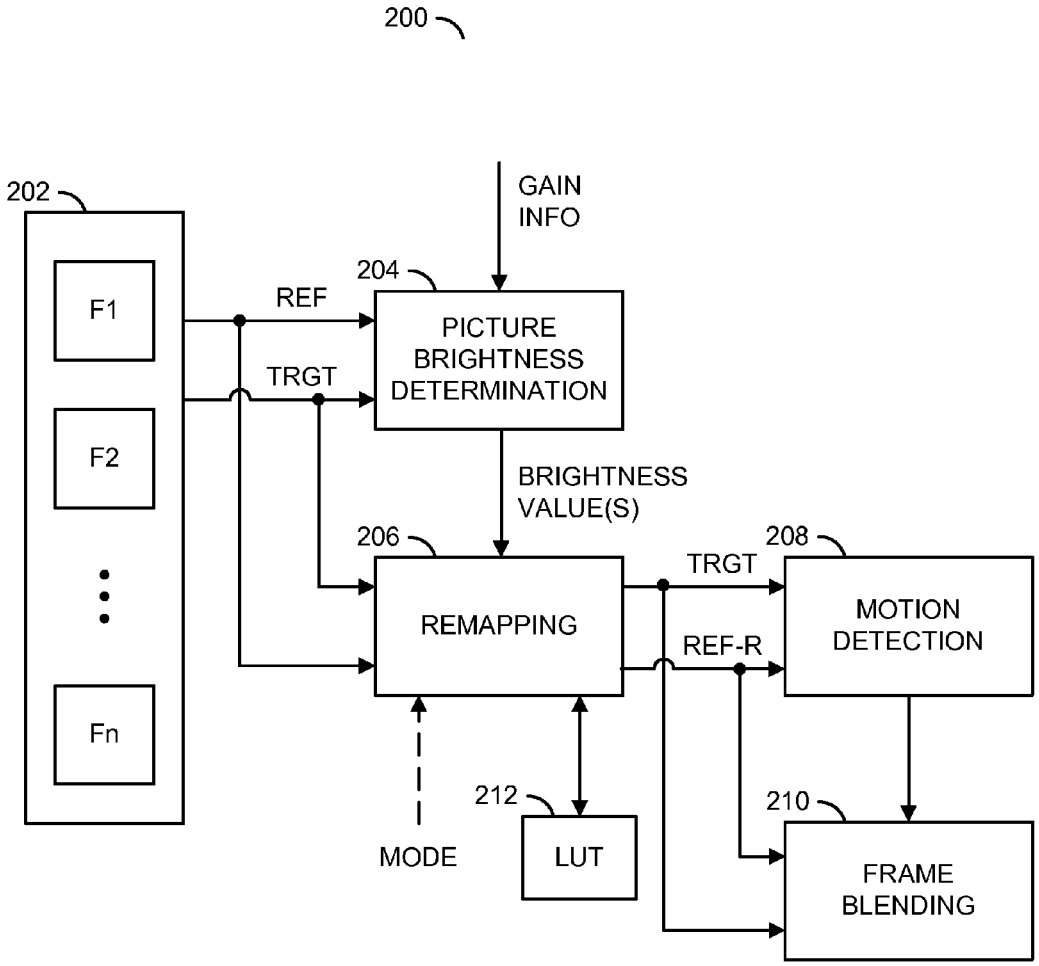
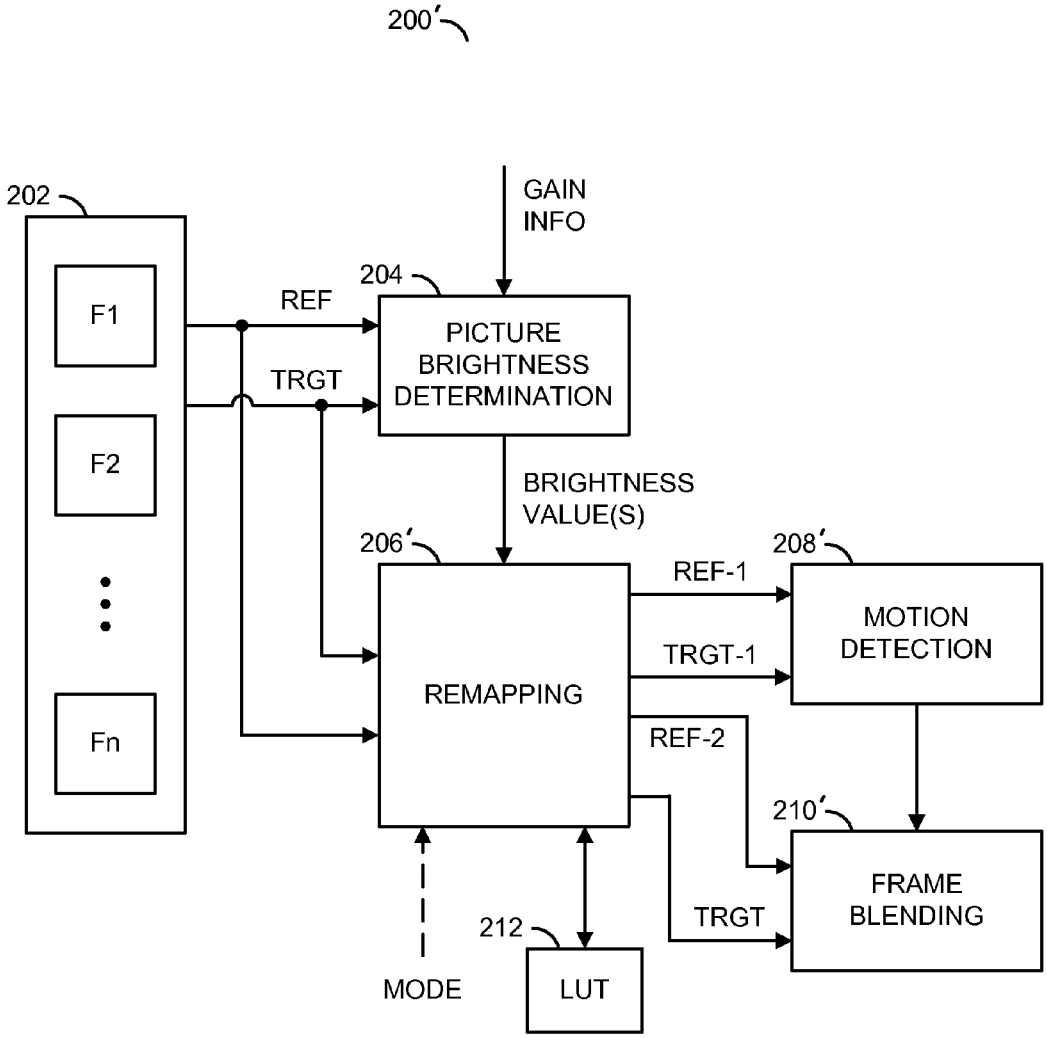

200
202
F1
F2
Fn
GAIN
INFO
204
REF
TRGT
PICTURE
BRIGHTNESS
DETERMINATION
BRIGHTNESS
VALUE(S)
206
REMAPPING
208
TRGT
REF-R
MOTION
DETECTION
212
LUT
MODE
210
FRAME
BLENDING

FIG. 2


200'
202
F1
F2
Fn
GAIN
INFO
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REF
TRGT
PICTURE
BRIGHTNESS
DETERMINATION
BRIGHTNESS
VALUE(S)
206'
REMAPPING
208'
REF-1
TRGT-1
MOTION
DETECTION
REF-2
210'
FRAME
BLENDING
TRGT
212
LUT
MODE

FIG. 3

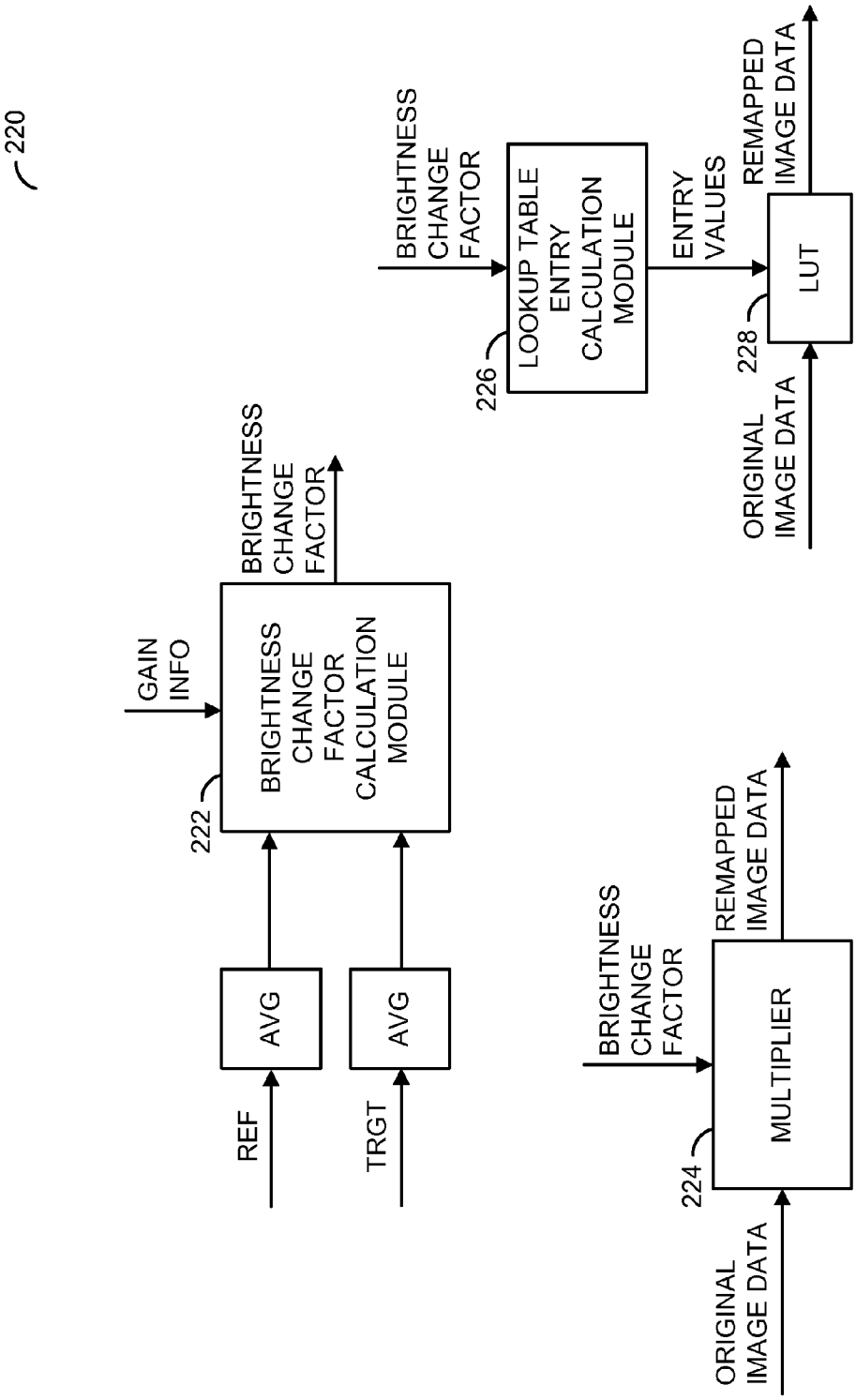
220
REF
TRGT
AVG
AVG
GAIN INFO
222
BRIGHTNESS CHANGE FACTOR CALCULATION MODULE
BRIGHTNESS CHANGE FACTOR
BRIGHTNESS CHANGE FACTOR
226
LOOKUP TABLE ENTRY CALCULATION MODULE
ENTRY VALUES
228
LUT
ORIGINAL IMAGE DATA
REMAPPED IMAGE DATA
BRIGHTNESS CHANGE FACTOR
224
MULTIPLIER
ORIGINAL IMAGE DATA
REMAPPED IMAGE DATA

FIG. 4

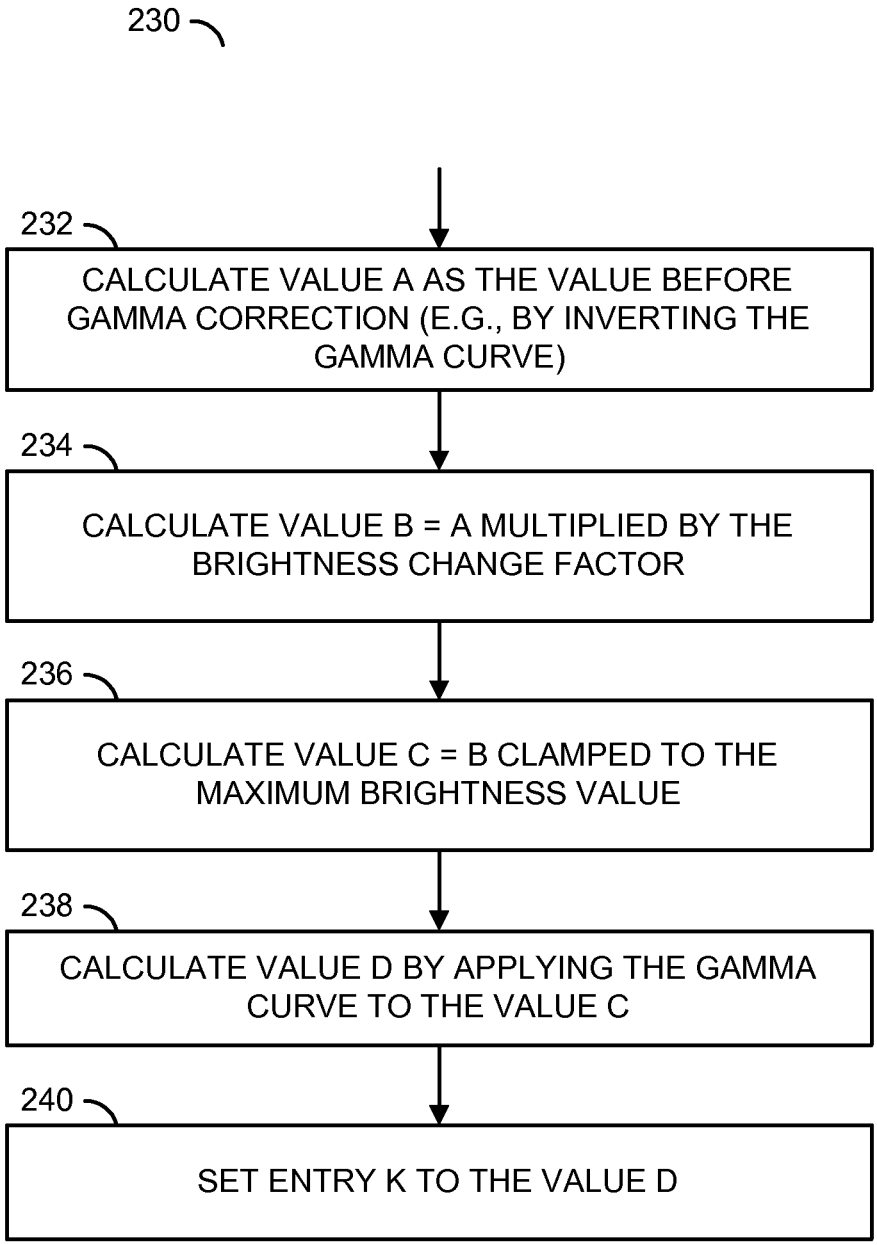
230
232
CALCULATE VALUE A AS THE VALUE BEFORE GAMMA CORRECTION (E.G., BY INVERTING THE GAMMA CURVE)
234
CALCULATE VALUE B = A MULTIPLIED BY THE BRIGHTNESS CHANGE FACTOR
236
CALCULATE VALUE C = B CLAMPED TO THE MAXIMUM BRIGHTNESS VALUE
238
CALCULATE VALUE D BY APPLYING THE GAMMA CURVE TO THE VALUE C
240
SET ENTRY K TO THE VALUE D

FIG. 5

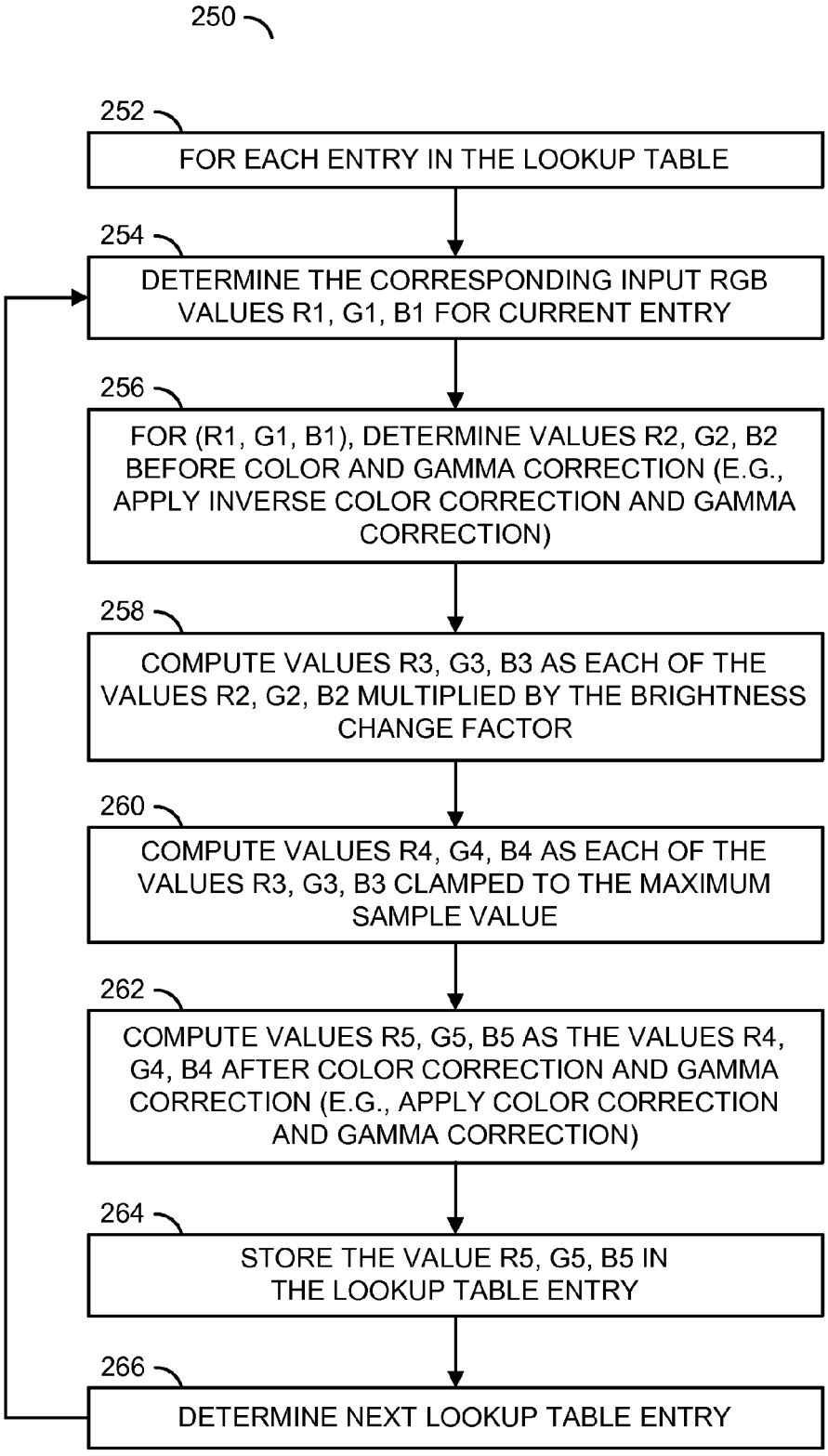
250
252
FOR EACH ENTRY IN THE LOOKUP TABLE
254
DETERMINE THE CORRESPONDING INPUT RGB VALUES R1, G1, B1 FOR CURRENT ENTRY
256
FOR (R1, G1, B1), DETERMINE VALUES R2, G2, B2 BEFORE COLOR AND GAMMA CORRECTION (E.G., APPLY INVERSE COLOR CORRECTION AND GAMMA CORRECTION)
258
COMPUTE VALUES R3, G3, B3 AS EACH OF THE VALUES R2, G2, B2 MULTIPLIED BY THE BRIGHTNESS CHANGE FACTOR
260
COMPUTE VALUES R4, G4, B4 AS EACH OF THE VALUES R3, G3, B3 CLAMPED TO THE MAXIMUM SAMPLE VALUE
262
COMPUTE VALUES R5, G5, B5 AS THE VALUES R4, G4, B4 AFTER COLOR CORRECTION AND GAMMA CORRECTION (E.G., APPLY COLOR CORRECTION AND GAMMA CORRECTION)
264
STORE THE VALUE R5, G5, B5 IN THE LOOKUP TABLE ENTRY
266
DETERMINE NEXT LOOKUP TABLE ENTRY

FIG. 6

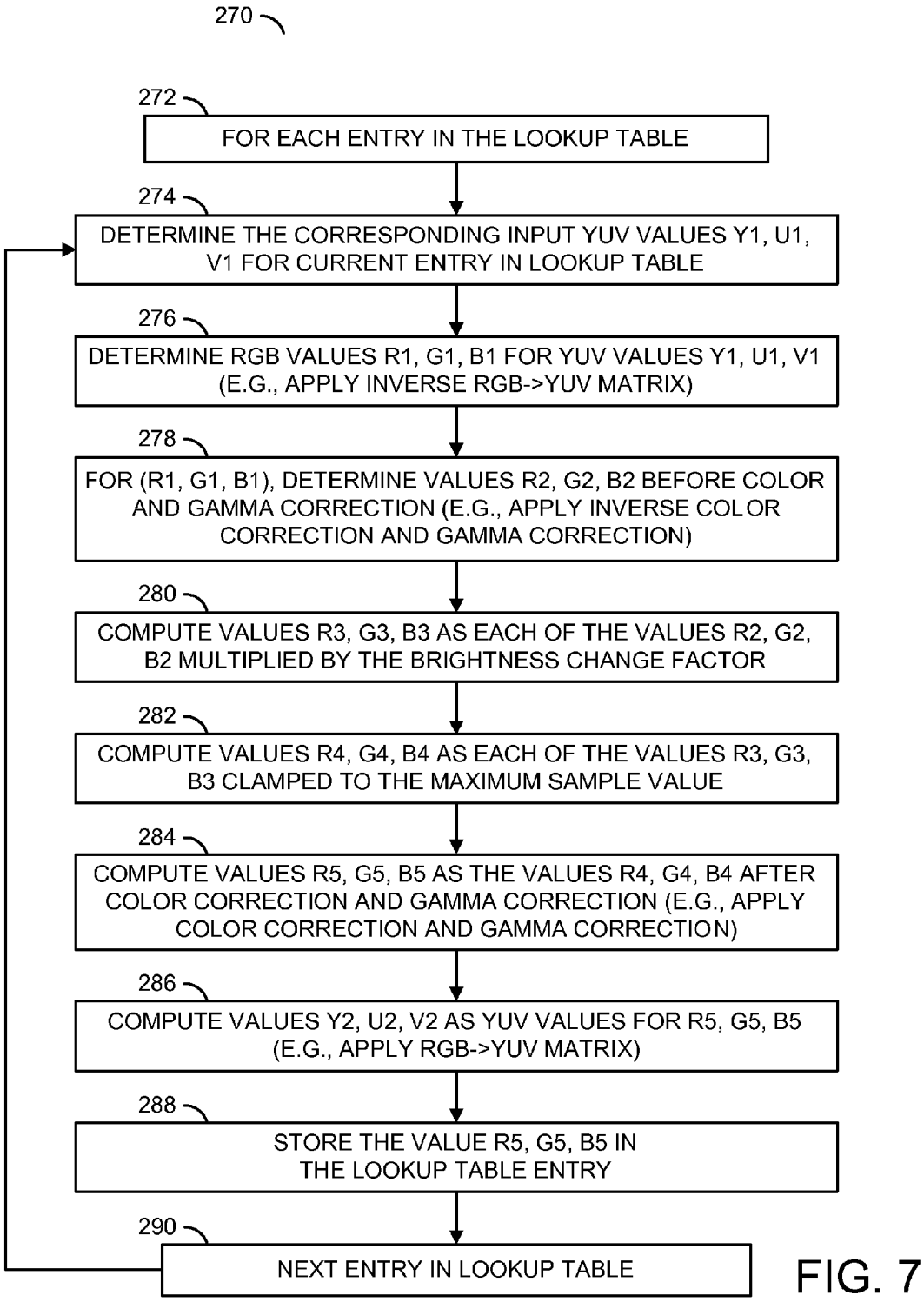
270
272
FOR EACH ENTRY IN THE LOOKUP TABLE
274
DETERMINE THE CORRESPONDING INPUT YUV VALUES Y1, U1, V1 FOR CURRENT ENTRY IN LOOKUP TABLE
276
DETERMINE RGB VALUES R1, G1, B1 FOR YUV VALUES Y1, U1, V1 (E.G., APPLY INVERSE RGB->YUV MATRIX)
278
FOR (R1, G1, B1), DETERMINE VALUES R2, G2, B2 BEFORE COLOR AND GAMMA CORRECTION (E.G., APPLY INVERSE COLOR CORRECTION AND GAMMA CORRECTION)
280
COMPUTE VALUES R3, G3, B3 AS EACH OF THE VALUES R2, G2, B2 MULTIPLIED BY THE BRIGHTNESS CHANGE FACTOR
282
COMPUTE VALUES R4, G4, B4 AS EACH OF THE VALUES R3, G3, B3 CLAMPED TO THE MAXIMUM SAMPLE VALUE
284
COMPUTE VALUES R5, G5, B5 AS THE VALUES R4, G4, B4 AFTER COLOR CORRECTION AND GAMMA CORRECTION (E.G., APPLY COLOR CORRECTION AND GAMMA CORRECTION)
286
COMPUTE VALUES Y2, U2, V2 AS YUV VALUES FOR R5, G5, B5 (E.G., APPLY RGB->YUV MATRIX)
288
STORE THE VALUE R5, G5, B5 IN THE LOOKUP TABLE ENTRY
290
NEXT ENTRY IN LOOKUP TABLE

FIG. 7

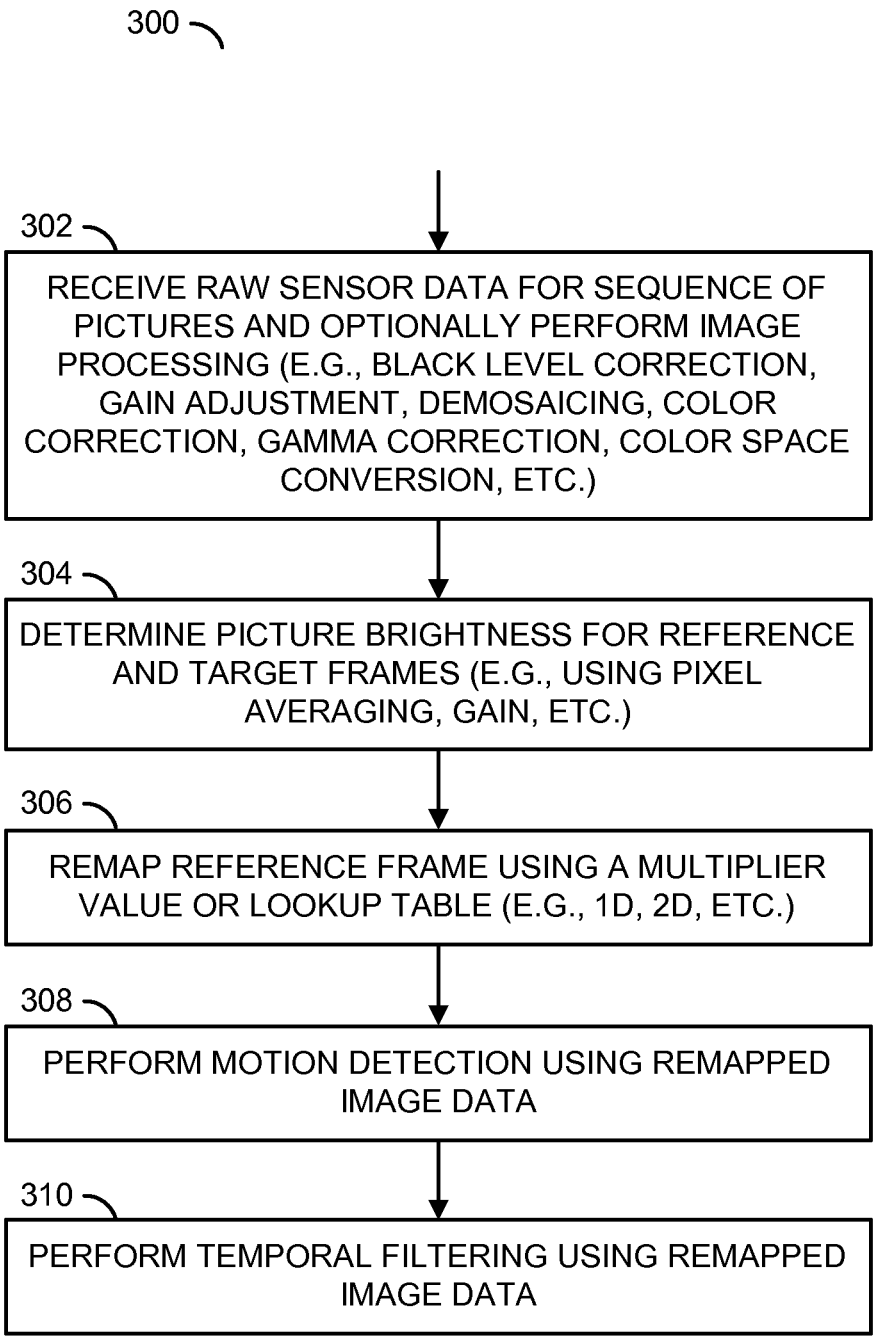
300
302
RECEIVE RAW SENSOR DATA FOR SEQUENCE OF PICTURES AND OPTIONALLY PERFORM IMAGE PROCESSING (E.G., BLACK LEVEL CORRECTION, GAIN ADJUSTMENT, DEMOSAICING, COLOR CORRECTION, GAMMA CORRECTION, COLOR SPACE CONVERSION, ETC.)
304
DETERMINE PICTURE BRIGHTNESS FOR REFERENCE AND TARGET FRAMES (E.G., USING PIXEL AVERAGING, GAIN, ETC.)
306
REMAP REFERENCE FRAME USING A MULTIPLIER VALUE OR LOOKUP TABLE (E.G., 1D, 2D, ETC.)
308
PERFORM MOTION DETECTION USING REMAPPED IMAGE DATA
310
PERFORM TEMPORAL FILTERING USING REMAPPED IMAGE DATA

FIG. 8

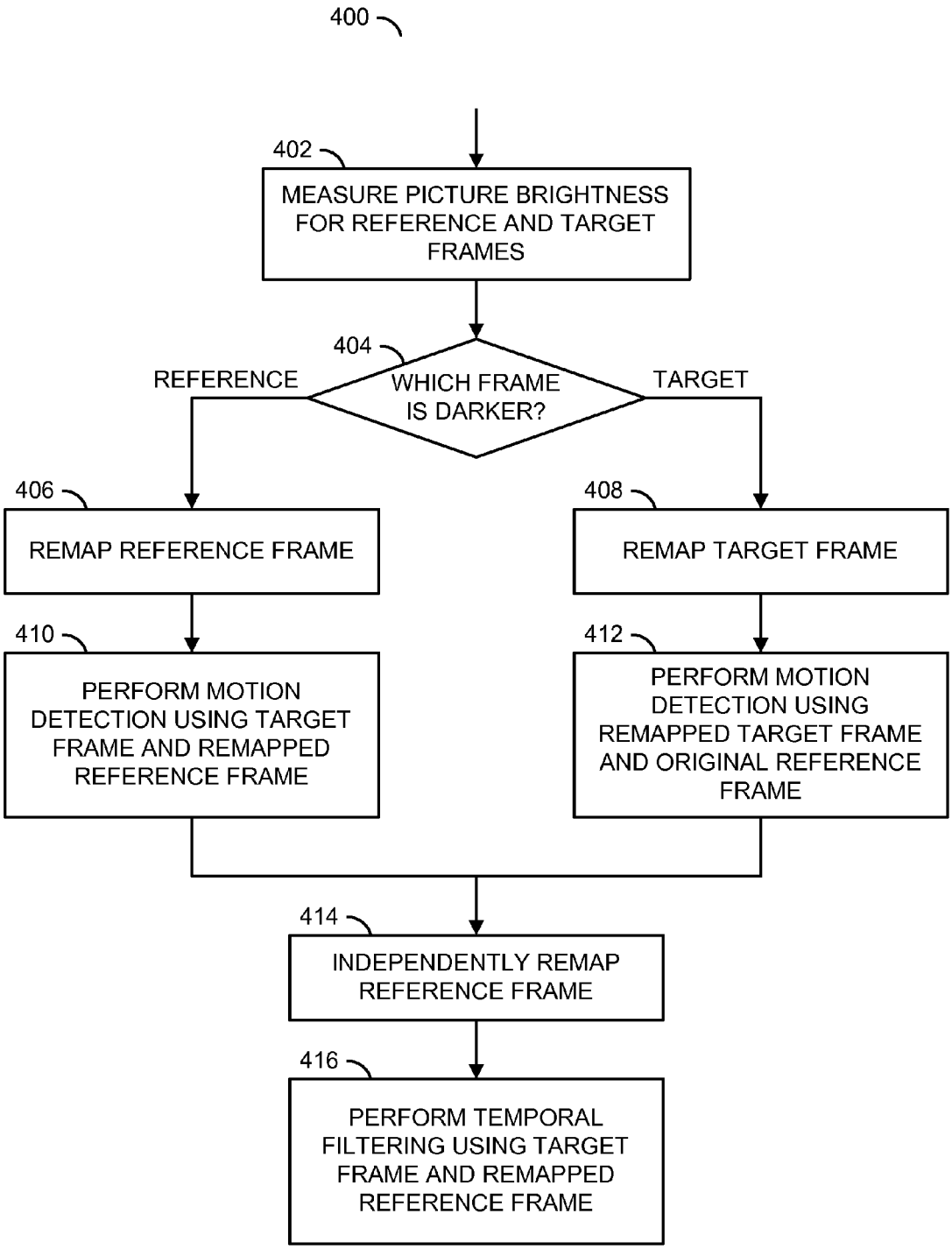
400
402
MEASURE PICTURE BRIGHTNESS FOR REFERENCE AND TARGET FRAMES
404
WHICH FRAME IS DARKER?
REFERENCE
TARGET
406
REMAP REFERENCE FRAME
408
REMAP TARGET FRAME
410
PERFORM MOTION DETECTION USING TARGET FRAME AND REMAPPED REFERENCE FRAME
412
PERFORM MOTION DETECTION USING REMAPPED TARGET FRAME AND ORIGINAL REFERENCE FRAME
414
INDEPENDENTLY REMAP REFERENCE FRAME
416
PERFORM TEMPORAL FILTERING USING TARGET FRAME AND REMAPPED REFERENCE FRAME

FIG. 9

PICTURE BRIGHTNESS ADJUSTED TEMPORAL FILTERING

This application relates to U.S. application Ser. No. 14/732,968, filed Jun. 8, 2015, U.S. application Ser. No. 14/580,867, filed Dec. 23, 2014, U.S. application Ser. No. 14/595,562, filed Jan. 13, 2015, U.S. application Ser. No. 14/667,950, filed Mar. 25, 2015, and U.S. Provisional Application No. 62/097,663, filed Dec. 30, 2014, which are hereby incorporated by reference in their entirety.

FIELD OF THE INVENTION

The present invention relates to video signal processing generally and, more particularly, to a picture brightness adjusted temporal filtering.

BACKGROUND OF THE INVENTION

Conventional motion compensated temporal filtering (MCTF) reduces noise by taking a weighted average of a current (or target) frame and one or more previous (or reference) frames. When the one or more previous frames are MCTF outputs, the filter is referred to as recursive. MCTF reduces noise because (if there is no motion, or if the motion is correctly modeled and compensated) the MCTF output is a weighted average of noisy samples of the same image sample which will statistically be less noisy than a single sample. In MCTF, each sample is a blended combination of the target frame and the reference frame. Motion detection (possibly relative to a motion model) is used to decide how much of the reference frame and how much of the target frame are used for the output of MCTF. If the target frame is brighter than the reference frame, then even if a particular sample is not moving, blending in the reference sample will have a spurious effect of making the output darker.

It would be desirable to implement brightness adjusted temporal filtering.

SUMMARY OF THE INVENTION

The present invention concerns an apparatus including an input circuit configured to receive a sequence of pictures and a processing circuit. The processing circuit may be configured to (i) determine respective picture brightness values for each of a reference picture and a target picture selected from the sequence of pictures, (ii) remap image data of the reference picture based upon the respective picture brightness values, and (iii) perform temporal filtering between the reference picture and the target picture utilizing the remapped image data.

The objects, features and advantages of the present invention include providing picture brightness adjusted temporal filtering that may (i) measure picture brightness of a frame prior to temporal filtering, (ii) remap picture data by scaling the picture data, (iii) remap picture data by applying an offset value, (iv) remap picture data by utilizing a lookup table, and/or (v) be implemented in one or more integrated circuits.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects, features and advantages of the present invention will be apparent from the following detailed description and the appended claims and drawings in which:

FIG. **1** is a diagram illustrating a video processing system in accordance with an example embodiment of the invention;

FIG. **2** is a diagram illustrating a picture brightness adjusted temporal filtering apparatus in accordance with an example embodiment of the invention;

FIG. **3** is a diagram illustrating a picture brightness adjusted temporal filtering apparatus in accordance with another example embodiment of the invention;

FIG. **4** is a diagram illustrating remapping techniques in accordance with example embodiments of the invention;

FIG. **5** is a flow diagram illustrating an example of determining values of entries in a lookup table in accordance with an example embodiment of the invention;

FIG. **6** is a flow diagram illustrating another example of determining values of entries in a lookup table in accordance with an example embodiment of the invention;

FIG. **7** is a flow diagram illustrating still another example of determining values of entries in a lookup table in accordance with an example embodiment of the invention;

FIG. **8** is a flow diagram illustrating a picture brightness adjusted temporal filtering process in accordance with an example embodiment of the invention; and

FIG. **9** is a flow diagram illustrating a picture brightness adjusted temporal filtering process in accordance with another example embodiment of the invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Referring to FIG. **1**, a block diagram of a camera system **100** is shown illustrating an example implementation of a camera/recorder system (or apparatus). In some embodiments, the camera system **100** may be a digital video camera, a digital still camera, or a hybrid digital video/still camera. In various embodiments, the electronics of the camera system **100** may be implemented as one or more integrated circuits. For example, an application specific integrated circuit (ASIC) or a system-on-a-chip (SOC) may be used to implement a processing portion of the camera system **100**.

In various embodiments, the camera system **100** may comprise a camera chip (or circuit) **102**, a lens assembly **104**, an image sensor **106**, an audio codec **108**, dynamic random access memory (DRAM) **110**, non-volatile memory (e.g., NAND flash memory, etc.) **112**, one or more serial interfaces **114**, an interface **116** for connecting to or acting as a universal serial bus (e.g., USB) host, an interface for connecting to a removable media **118** (e.g., SD—secure digital media, SDXC—secure digital extended capacity media, etc.), a wireless interface **120** for communicating with a portable user device, a microphone **122** for recording audio, and a speaker **124** for playing audio. In some embodiments, the lens assembly **104** and the image sensor **106** may be part of a separate camera connected to the processing portion of the system **100** (e.g., via a video cable, a high definition media interface (e.g., HDMI) cable, a USB cable, an ethernet cable, or wireless link).

In various embodiments, the circuit **102** may comprise a number of modules (or circuits) including, but not limited to, a pulse width modulation (e.g., PWM) module, a real time clock and watchdog timer (RTC/WDT), a direct memory access (DMA) engine, a high-definition multimedia interface (e.g., HDMI), an LCD/TV/Parallel interface, a general purpose input/output interface (e.g., GPIO) and analog-to-digital converter (e.g., ADC) module, an infrared (IR) remote interface, a secure digital input output interface (e.g., SDIO) module, a secure digital (e.g., SD) card interface, an audio I^2S interface, an image sensor input interface, and a synchronous data communications interface (e.g., IDC SPI/SSI). The circuit **102** may also include an embedded processor (e.g., ARM, etc.), an image digital signal processor (DSP), and a

video and/or audio DSP. In embodiments incorporating the lens assembly **104** and image sensor **106** in the system **100**, the circuit **102** may be configured (e.g., programmed) to control the lens assembly **104** and receive image data from the sensor **106**. The wireless interface **120** may include support for wireless communication by one or more wireless protocols such as Bluetooth®, ZigBee®, and/or one or more Institute of Electrical and Electronics Engineering (IEEE) protocol standards (e.g., IEEE 802.11, IEEE 802.15, IEEE 802.15.1, IEEE 802.15.2, IEEE 802.15.3, IEEE 802.15.4, IEEE 802.15.5, IEEE 802.20, etc). The circuit **102** may also include communication support using one or more universal serial bus (USB) protocols (e.g., 1.0, 2.0, 3.0, etc.). The circuit **102** may also be configured to be powered via the USB connection. However, other communication and/or power interfaces may be implemented accordingly to meet the design criteria of a particular implementation.

In various embodiments, programming code (e.g., executable instructions for controlling various processors of the circuit **102**) implementing picture brightness adjusted temporal filtering in accordance with an embodiment of the invention may be stored in one or more of the memories **110** and **112**. When executed by the circuit **102**, the programming code generally enables the circuit **102** to capture a sequence of pictures from the sensor **106**, determine respective picture brightness values for a pair of pictures (e.g., a reference picture and a target picture) selected from the sequence of pictures, remap image data of the reference picture, and perform both a motion detection operation and a temporal filtering (blending) operation between the reference and the target pictures using the remapped reference picture data. In some embodiments, the programming code generally enables the circuit **102** to remap image data of either the reference picture or the target picture and perform the motion detection operation between the reference and the target pictures using the remapped picture data, and independently remap the image data of the reference picture and perform the temporal filtering operation between the reference and the target pictures using the independently remapped reference picture data. In embodiments implementing the remapping of either the reference picture or the target picture for use with the motion detection, the circuit **102** may select the particular picture whose image data is remapped prior to performing motion detection based on a configuration setting, a user input (e.g., a mode control), and/or a predetermined criterion.

Motion compensated temporal filtering (MCTF) combines a current (or target) picture with one or more motion compensated previous (or reference) pictures. The reference picture(s) may either have already undergone MCTF or not; most commonly it(they) has(have). Motion compensation may be viewed as adjusting (or warping) a first picture to match a second picture. The warping may be done in many ways: 1) block based (e.g., use a different motion vector for each block); 2) model based, such as pan, zoom, or tilt; 3) no change. The latter case is appropriate for a fixed (not moving) camera such as a mounted security camera. Since a large portion of each picture may be assumed to be stationary, for many pixels the result will be exactly correct, even though the result will always be wrong where there is motion.

Motion detection in connection with temporal filtering or blending refers to whether the current picture is different from the motion compensated reference picture. In other words, is blending in the reference picture likely to cause motion artifacts or not. When the "no change" motion compensation strategy (e.g., above) is used, motion detection addresses whether there is motion at the current sample. If a different strategy is used, motion detection addresses whether the motion model used for motion compensation is correct at the particular pixel sample. The result of motion detection may be used to determine how to blend the current picture sample and the reference picture sample. In one example, a conventional technique the filtered result equals Alpha*T+(1−Alpha)*R, where T represents the target picture sample, R represents the reference picture sample, and Alpha represents a blending value. In one example, the blending value Alpha may be selected from a lookup table based on an absolute difference (e.g., D) between the target picture sample and the reference picture sample (e.g., Alpha=lookup(D), D equals the absolute value of (T−R)).

Referring to FIG. **2**, a diagram is shown illustrating a picture brightness adjusted temporal filtering apparatus in accordance with an example embodiment of the invention. In various embodiments, a picture brightness adjusted temporal filtering apparatus **200** may comprise a block (or circuit) **202**, a block (or circuit) **204**, a block (or circuit) **206**, a block (or circuit) **208**, and a block (or circuit) **210**. The block **202** may be configured to receive and store a number or sequence of pictures or frames (e.g., F**1**, . . . , Fn). The block **204** may be configured to determine picture brightness values for a reference picture (e.g., REF) and a target picture (e.g., TRGT) selected from the pictures stored in the block **202**. In various embodiments, the block **204** may determine the picture brightness values based on actual measurements, gain information (e.g., analog, digital, or both analog and digital gains associated with each picture), or any combination thereof.

In some embodiments, the block **206** may be configured to remap the image data of only the reference picture based on the picture brightness values generated in the block **204** for presentation to the blocks **208** and **210**. The block **206** operating in conjunction with the blocks **208** and **210** generally implements a picture brightness based temporal filtering adjustment technique in accordance with an embodiment of the invention. In some embodiments, the block **206** may be configured to remap the image data of the reference picture using a determined multiplier factor. In some embodiments, the block **206** may be configured to remap the image data of the reference picture using determined values in a lookup table (e.g., LUT **212**). In some embodiments, the LUT **212** is implemented separately from the block **206**. In some embodiments, the LUT **212** may be implemented as part of the block **206**.

In various embodiments, the block **208** may be configured to perform motion detection between the target picture (TRGT) and a remapped reference picture (REF-R) received from the block **206**, where the target picture (TRGT) has the original image data retrieved from the block **202** and the remapped reference picture (REF-R) has the remapped image data. In some embodiments, the block **208** may be configured to receive only the remapped image data of the reference picture from the block **206** and retrieve the original image data of the target picture from the block **202**. In various embodiments, the block **210** may be configured to perform temporal filtering between the target picture (TRGT) and the remapped reference picture (REF-R) received from the block **206**, where the target picture (TRGT) has the original image data retrieved from the block **202** and the remapped reference picture (REF-R) has the remapped image data. In some embodiments, the block **210** may be configured to receive only the remapped image data of the reference picture from the block **206** and retrieve the original image data of the target picture from the block **202**.

In one example, the block **202** may be implemented as part of an input circuit configured to receive a sequence of pictures and the blocks **204-210** may be implemented by a processing

circuit configured to manipulate image data using techniques in accordance with the present invention. In some embodiments, the block **202** may comprise or be associated with one or more storage media (e.g., dynamic random access memory (DRAM), static random access memory (SRAM), Flash memory, etc.) configured to store the sequence of pictures. In some embodiments, the sequence of pictures may be stored in an external memory device, and the reference and target pictures brought into a faster internal memory associated with (tightly coupled to) a processor (e.g., DSP, MPU, CPU, etc.) configured to motion compensate the pictures in accordance with an embodiment of the invention. In some embodiments, the remapped image data may be written back to memory by the block **206** and read from memory by the blocks **208** and **210**.

Referring to FIG. **3**, a diagram is shown illustrating a picture brightness adjusted temporal filtering apparatus **200'** in accordance with another example embodiment of the invention. In some embodiments, a block **206'** may be implemented in place of the block **206** of FIG. **2**. The block **206'** generates (i) a signal (e.g., REF-1) and a signal (e.g., TRGT-1) for presentation to the block **208** and a signal (e.g., REF-2) for presentation along with the target picture (e.g., TRGT) to the block **210**. The signals REF-1 and TRGT-1 are generated by remapping the image data of either the reference picture (e.g., REF) or the target picture (TRGT) based on the picture brightness values generated in the block **204**. The signal REF-2 is generated by independently remapping the image data of the reference picture (e.g., REF) based on the picture brightness values generated in the block **204** for presentation to the block **210**.

In some embodiments, the block **206'** determines which of the reference and target pictures gets remapped for motion detection based upon which picture is darker than the other. In some embodiments, the block **206'** determines which of the reference and target pictures gets remapped for motion detection based upon a mode input (e.g., MODE). In some embodiments, the block **206'** may be configured to remap the selected image data using a determined multiplier factor. In some embodiments, the block **206'** may be configured to remap the selected image data using determined values in a lookup table (e.g., LUT **212**). In some embodiments, the LUT **212** is implemented separately from the block **206'**. In some embodiments, the LUT **212** may be implemented as part of the block **206'**.

The block **206'** is generally configured to independently remap the image data of the reference picture for temporal filtering performed by the block **210**. In some embodiments, the block **206'** may be configured to remap the image data of the reference picture using a determined multiplier factor. In some embodiments, the block **206'** may be configured to remap the image data of the reference picture using determined values in a lookup table (e.g., LUT **212**). In some embodiments, the LUT **212** is implemented separately from the block **206'**. In some embodiments, the LUT **212** may be implemented as part of the block **206'**.

In various embodiments, the block **208** may be configured to perform motion detection between the target and reference pictures received from the block **206'**, where one picture has remapped image data and the other picture has the original image data retrieved from the block **202**. In some embodiments, the block **208** may be configured to receive only the remapped image data of the adjusted picture from the block **206'** and retrieve the original image data of the unadjusted picture from the block **202**. In various embodiments, the block **210** may be configured to perform temporal filtering between the target and reference pictures received from the block **206'**, where the reference picture has remapped image data and the target picture has the original image data retrieved from the block **202**. In some embodiments, the block **210** may be configured to receive only the remapped image data of the reference picture from the block **206'** and retrieve the original image data of the target picture from the block **202**.

In one example, the block **202** may be implemented as part of an input circuit configured to receive a sequence of pictures and the blocks **204-210** may be implemented by a processing circuit configured to manipulate image data using techniques in accordance with the present invention. In some embodiments, the block **202** may comprise or be associated with one or more storage media (e.g., dynamic random access memory (DRAM), static random access memory (SRAM), Flash memory, etc.) configured to store the sequence of pictures. In some embodiments, the sequence of pictures may be stored in an external memory device, and the reference and target pictures brought into a faster internal memory associated with (tightly coupled to) a processor (e.g., DSP, MPU, CPU, etc.) configured to motion compensate the pictures in accordance with an embodiment of the invention. In some embodiments, the remapped image data may be written back to memory by the block **206'** and read from memory by the blocks **208** and **210**.

In various embodiments, picture brightness is used to remap the reference picture data and/or the target picture data prior to motion detection and temporal filtering. The motion detection and temporal filtering may be performed, but are not limited to, using conventional motion detection and temporal filtering techniques. In various embodiments, the picture (or frame) brightness may be determined based on one or more of (i) a known analog gain used on the sensor **106**, (ii) a known digital gain used on the sensor **106** or applied after the sensor **106**, and (iii) an actual measured picture brightness. In one example, picture brightness may be measured by averaging pixel values received from the sensor **106**.

Various techniques may be implemented to remap the image data of either the reference picture or the target picture. In some embodiments, remapping comprises multiplying the image data of the selected picture using an appropriate multiplication factor or multiplier. For example, in an embodiment where the target picture is to be remapped for motion detection, if the reference picture is determined to be 10% brighter than the target picture, the image data of the target picture may be multiplied by a factor of 1.1. In various embodiments, samples (image data) may be remapped using values in a lookup table. In some embodiments, samples may be remapped using a one-dimensional (1D) lookup table. Embodiments implementing a 1D lookup table for motion detection may be used for:

1. sum-of-absolute-difference (SAD) on luminance (luma) samples (e.g., using a luma→luma lookup); and
2. SAD on red, green, and blue (RGB) samples (e.g., using R→R, B→B and G→G lookup).

Embodiments implementing a 1D lookup table for temporal filtering may be used for:

1. MCTF blending on luminance (luma) samples (e.g., using a luma→luma lookup); and
2. MCTF blending on red, green, and blue (RGB) samples (e.g., using R→R, B→B and G→G lookup).

Remapping the samples using the 1D lookup table may provide better performance than multiplying the samples by a multiplier when the samples on which the SAD or MCTF blending is being performed are not linearly related to the picture brightness (e.g., when the samples have been gamma corrected).

In some embodiments, a multi-dimensional (nD) lookup table may be used. The multi-dimensional lookup table may be implemented as many-to-1 or many-to-many. Embodiments implementing the multi-dimensional lookup may include, but are not limited to:

1. RGB-RGB lookup, SAD on RGB (many-to-many);

2. RGB→RGB lookup, MCTF blending on RGB (many-to-many);

3. YUV→YUV lookup, SAD on YUV (many-to-many); and

4. YUV→YUV lookup, MCTF blending on YUV (many-to-many); and

5. YUV→Y lookup, SAD on Y (luma) only (many-to-1).

6. YUV→Y lookup, MCTF blending on Y (luma) only (many-to-1).

Embodiments implementing the multi-dimensional lookup may perform better than embodiments implementing the 1D lookup when the samples on which the SAD or MCTF blending is being performed have undergone a mixture of channels (e.g., color correction).

Various embodiments (or modes) may be implemented with respect to which picture (or frame) is remapped for motion detection. In a first embodiment (or mode), the reference frame is always remapped. In a second embodiment (or mode), the target frame is always remapped. In a third embodiment (or mode), an adaptive technique may be implemented where the remapped image is selected based upon some criterion (e.g., the darker frame is remapped, etc.). Embodiments implementing the adaptive technique may provide better results when some samples in the brighter frame are at saturation (e.g., equal to a maximum possible value) and cannot be reliably remapped. For example, in a system where the sample values can range from 0 to 255, beyond a certain brightness level all brightness levels will be represented as sample value of 255. If a sample in the brighter frame has a value of 255, the underlying amount of light that the pixel represents could be arbitrarily high. If the frame brightness should be reduced by 10%, there is no way to know how much the remapped value should be lower than 255 or if the remapped value should be lower than 255 at all. In embodiments where multiple modes are available to remap the image data for motion detection, a signal (e.g., MODE) may be implemented to allow selection of a particular mode to be applied.

Referring to FIG. **4**, a diagram is shown illustrating example implementations of remapping apparatus in accordance with embodiments of the invention. In various embodiments, a brightness change factor may be determined, for example, based on gain information and/or measurements of picture brightness (e.g., average pixel values, etc.) of the reference and target pictures. In some embodiments, a multiplier circuit may be used to remap image data. A multiplier factor can, for example, be computed based upon the brightness change factor between two pictures. In some embodiments, a lookup table may be generated to remap image data.

In one example, an apparatus (or system or camera) **220** may implement a picture brightness adjusted temporal filtering process in accordance with an embodiment of the invention. In various embodiments, the apparatus **220** may comprise a block (or circuit) **222**, a block (or circuit) **224**, a block (or circuit) **226**, and a block (or circuit) **228**. The block **222** may implement a brightness change factor calculation module. The block **224** may implement a multiplier. The block **226** may implement a lookup table entry calculation module. The block **228** may implement a lookup table. The lookup table **228** may be used as the LUT **212** in FIGS. **2** and **3**.

The block **222** may receive a measurement of picture brightness (e.g., an average pixel value, etc.) for the reference picture, a measurement of picture brightness (e.g., an average pixel value, etc.) for the target picture, and gain information (e.g., GAIN INFO) for both the reference and the target pictures. The gain information may include analog and/or digital gain values associated with each the reference picture and the target picture. The block **222** is configured to generate a brightness change factor based on one or more of the gain information for the reference picture, the gain information for the target picture, the average pixel value for the reference picture, and/or the average pixel value for the target picture. The block **224** may be configured to generate remapped image data for the selected picture by multiplying the original image data of the selected picture by the brightness change factor. The block **226** may be configured to calculate entry values for the block **228** based in part upon the brightness change factor. The block **228** may be configured to generate remapped image data for the selected picture in response to the original image data of the selected picture.

In one example, the reference picture may use a first gain (e.g., G**1** dB) and the target picture may use a second gain (e.g., G**2** dB). The first and second gains may be digital, analog, or a combination of digital and analog. If the only difference in brightness is due to a difference in the gains (e.g., G**1** does not equal G**2**), the difference in brightness between the reference and the target pictures may be expressed in terms of the respective gains (e.g., the target picture is $10^{((G2-G1)/20)}$ times brighter than the reference picture). For example, if the reference picture uses a gain of 10 dB and the target picture uses a gain of 11 dB, the target picture is about 1.122 times brighter than the reference picture.

In a second example, if the measurement of picture brightness (e.g., the average pixel value) of the target picture is 5% higher than the measurement of picture brightness (e.g., the average pixel value) of the reference picture, the target picture may be said to be 1.05 times brighter than the reference picture. The average pixel value is typically measured after an analog gain is applied and before a digital gain is applied. When the average pixel value is measured after application of the analog gain and before application of the digital gain, if average pixel values and gains are used to determine brightness values, then only the digital gain differences need be taken into consideration because any analog gain differences are already accounted for by the averaging of the pixel value measurements.

In a third example, if (i) the measurement of picture brightness (e.g., the average pixel value) of the target picture is 5% higher than the measurement of picture brightness (e.g., the average pixel value) of the reference picture, (ii) the reference picture uses a digital gain of 10 dB, and (iii) the target picture uses a digital gain of 11 dB, the target picture would be determined to be about 1.178 (e.g., 1.122×1.05 equals approximately 1.178) times brighter than the reference picture.

When the picture brightness differences are compensated for by remapping image data of the reference picture by using a multiplier, then in examples 1, 2, and 3 above the samples in the target picture would be multiplied by 1.122, 1.05, and 1.178, respectively. If the modification of the reference picture is done after gamma (tone) correction and done with a one dimensional lookup table (e.g., the lookup table **244** implemented as a 1D LUT), the lookup table **244** may be programmed (e.g., the values of the lookup table entries may

be determined) based upon the factor calculated in the block **222** as described below in connection with the examples illustrated in FIGS. **5-7**.

Referring to FIG. **5**, a flow diagram is shown illustrating a process **230** for determining values of entries in a lookup table in accordance with an example embodiment of the invention. The process (or method) is illustrated for a table with 64 entries (e.g., indices 0-63) and sample values [0,255]. The value of an entry K, where K is in [0,63], may be determined as follows. In a step (or state) **232**, for a pixel with K/64 of the maximum value after gamma correction, the process **230** calculates a value A as the pixel value before gamma correction (e.g., by inverting the gamma curve). In a step (or state) **234**, the process **230** calculates a value B equal to the value A multiplied by the brightness change factor (e.g., by 1.122, 1.05, and 1.178, respectively, in examples 1, 2, and 3 above). In a step (or state) **236**, the process **230** calculates a value C equal to the value B clamped to the maximum brightness value. In a step (or state) **238**, the process **230** calculates a value D by applying the gamma curve to the value C. In a step (or state) **240**, the process **230** sets the entry K to the value D.

In the above example, the number of table entries (64) is fewer than the number of sample values (256), so when the lookup table is used interpolation is needed. For example, an input sample with a value of 16 would use the entry at index **4**, but an input sample with a value of 17 would use three-fourths times the entry at index **4** plus one-fourth times the entry at index **5**. In another embodiment, a table with 256 entries may be used to avoid interpolation.

Referring to FIG. **6**, a flow diagram is shown illustrating a process **250** for determining values of entries in a lookup table in accordance with an example embodiment of the invention. When the modification (remapping) of the image data of the reference picture is done (i) on RGB samples after color correction and gamma (tone) correction and (ii) with a 3D→3D lookup table, the lookup table may be programmed, in one example, using the process **250**. In a step (or state) **252**, the process **250** begins determining values for each entry in the lookup table. In a step **254**, the process **250** determines the corresponding input RGB values, R**1**, G**1**, B**1** for a current entry. In a step (or state) **256**, the process **250** determines values R**2**, G**2**, B**2** corresponding to (R**1**, G**1**, B**1**) before color and gamma correction (e.g., by applying inverse color correction and gamma correction). In a step (or state) **258**, the process **250** computes values R**3**, G**3**, B**3** as each of the values R**2**, G**2**, B**2** multiplied by the brightness change factor (e.g., by multiplying values R**3**, G**3**, B**3** by 1.122, 1.05, and 1.178, respectively, from examples 1, 2, and 3 above). In a step (or state) **260**, the process **250** computes values R**4**, G**4**, B**4** as each of the values R**3**, G**3**, B**3** clamped to the maximum sample value. In a step (or state) **262**, the process **250** computes values R**5**, G**5**, B**5** as the values R**4**, G**4**, B**4** after color correction and gamma correction (e.g., by applying color correction and gamma correction to the values R**4**, G**4**, B**4**). In a step (or state) **264**, the process **250** stores the values R**5**, G**5**, B**5** in the current lookup table entry. In the step **266**, the process **250** moves to the step **254** to determine the next lookup table entry. The process **250** continues until all the entries of the entire lookup table have been determined.

Referring to FIG. **7**, a flow diagram is shown illustrating a process **270** for determining the values of entries in a lookup table in accordance with another example embodiment of the invention. If the modification (remapping) of the reference picture is done on YUV samples after color correction and gamma (tone) correction applying an RGB→YUV matrix, and if the modification is done with a 3D→3D (YUV→YUV) lookup table, the lookup table may be programmed, for example, using the process **270**.

In a step (or state) **272**, the process **270** may determine values for each entry in the table. In a step **274**, the process **270** may determine the corresponding input YUV values, Y**1**, U**1**, V**1** for a current lookup table entry. In a step (or state) **276**, the process **270** calculates the RGB values R**1**, G**1**, B**1** for the YUV values Y**1**, U**1**, V**1** (e.g., by inverting the RGB→YUV matrix). In a step (or state **278**, the process **270** determines values R**2**, G**2**, B**2** corresponding to (R**1**, G**1**, B**1**) before color and gamma correction (e.g., by applying inverse color correction and gamma correction). In a step (or state) **280**, the process **270** calculates the values R**3**, G**3**, B**3** as each of the values R**2**, G**2**, B**2** multiplied by the brightness change factor (e.g., by multiplying the values R**2**, G**2**, B**2** by 1.122, 1.05, and 1.178, respectively, in examples 1, 2, and 3 above). In a step (or state) **282**, the process **270** calculates the values R**4**, G**4**, B**4** as each of the values R**3**, G**3**, B**3** clamped to the maximum sample value. In a step (or state) **284**, the process **270** calculates the values R**5**, G**5**, B**5** as the values R**4**, G**4**, B**4** after color correction and gamma correction (e.g., by applying color correction and gamma correction to the values R**4**, G**4**, B**4**). In a step **286**, the process **270** calculates the values Y**2**, U**2**, V**2** as the YUV values for R**5**, G**5**, B**5** (e.g., by applying the RGB→YUV matrix). In a step or (state) **288**, the process **270** stores the values Y**2**, U**2**, V**2** as the lookup table entry. In a step (or state) **290**, the process **270** moves to the step **274** to determine the next lookup table entry. The process **270** continues until all the entries of the entire lookup table have been determined.

If the modification (remapping) of the reference picture is done on YUV samples after color correction and gamma (tone) correction applying an RGB→YUV matrix, and if the modification is done with a 3D→1D (YUV→Y) lookup table, the lookup table may be programmed, for example, similarly to the description above, but only Y**2**, and not U**2** and V**2**, may be computed.

Remapping the reference picture using RGB→RGB, YUV→YUV or YUV→Y lookup tables utilizes a lookup in a 3D table. In one implementation, the 3D table may cover all possible values of the input. Such an implementation could be quite costly. For example, if each input can have 256 values (0-255), then the 3D table would need 256^3=16,777,216 entries. A more practical implementation may use a smaller table (e.g., 16×16×16 or 32×32×32) and interpolation of the table (for remapping the selected picture). The interpolation of the table may be achieved using conventional techniques such as those disclosed in U.S. Pat. No. 4,275,413.

Referring to FIG. **8**, a flow diagram is shown illustrating a picture brightness adjusted temporal filtering method **300** in accordance with an example embodiment of the present invention. The method (or process) **300** may be performed by the circuit **102**. The method **300** generally comprises a step (or state) **302**, a step (or state) **304**, a step (or state) **306**, a step (or state) **308**, and a step (or state) **310**. The steps **302-310** may be implemented in an apparatus (or circuit or device) using hardware, software, firmware, or any combination thereof.

In the step **302**, the circuit **102** may receive raw sensor data (e.g., from the sensor **106** via the sensor input block). Optional image processing steps (e.g., black level correction, gain (e.g. digital) adjustment, demosaicing, color correction matrix, gamma correction, color space conversion, etc.) may be performed, for example, using the digital signal processing (DSP) blocks of the circuit **102**. In the step **304**, the circuit **102** may determine picture brightness for each of the reference and the target frames (e.g., REF and TRGT, respectively). In

some embodiments, the picture brightness of each frame is determined by actual measurement (e.g., averaging pixel values, etc.). In some embodiments, the picture brightness is determined based on a gain (digital and/or analog) applied to the picture. In still other embodiments, the particular method used to determined picture brightness is configurable. In the step **306**, the circuit **102** remaps the reference picture using a predetermined technique (e.g., using a multiplier value, a 1D lookup, a multi-dimensional lookup, etc.). In some embodiments, the particular remapping technique used is configurable. In the step **308**, the circuit **102** performs motion detection utilizing the remapped picture data. The motion detection may be performed according to, but is not limited to, conventional techniques. In the step **310**, the circuit **102** performs temporal filtering utilizing the remapped picture data. The temporal filtering may be performed according to, but is not limited to, conventional techniques.

Referring to FIG. **9**, a flow diagram is shown illustrating a picture brightness adjusted temporal filtering method **400** in accordance with another example embodiment of the present invention. The method (or process) **400** may be performed by the circuit **102**. The method **400** generally comprises a step (or state) **402**, a step (or state) **404**, a step (or state) **406**, a step (or state) **408**, a step (or state) **410**, a step (or state) **412**, a step (or state) **414**, and a step (or state) **416**. The steps **402-416** may be implemented in an apparatus (or circuit or device) using hardware, software, firmware, or any combination thereof.

In the step **402**, the circuit **102** may determine picture brightness for each of the reference and the target frames (e.g., REF and TRGT, respectively). In some embodiments, the picture brightness of each frame is determined by actual measurement. In some embodiments, the picture brightness is determined based on a gain (digital and/or analog) applied to the picture. In still other embodiments, the particular method used to determined picture brightness is configurable. In the step **404**, the circuit **102** may select, for example, the darker frame to be remapped. However, other criteria may be implemented accordingly to meet the design criteria of a particular implementation. When the reference frame is darker than the target frame, the process **400** moves to the step **406**. When the reference frame is brighter than the target frame, the process **400** moves to the step **408**. In the step **406**, the circuit **102** remaps the image data of the reference frame. In the step **408**, the circuit **102** remaps the image data of the target frame. The circuit **102** remaps the data of the selected frame using a predetermined technique (e.g., using a multiplier, a 1D lookup, or a multi-dimensional lookup). In some embodiments, the particular remapping technique used is configurable.

When the image data of the reference frame has been remapped in the step **406**, the process **400** moves to the step **410**. When the image data of the target frame has been remapped in the step **408**, the process **400** moves to the step **412**. In the step **410**, the circuit **102** performs motion detection utilizing the remapped image data of the reference frame and the original data of the target frame. In the step **412**, the circuit **102** performs motion detection utilizing the remapped image data of the target frame and the original data of the reference frame. When the motion detection of the step **410** or the step **412** is completed, the process **400** moves to the step **414**. In the step **414**, the circuit **102** independently remaps the image data of the reference frame. When the image data of the reference frame has been remapped in the step **414**, the process **400** moves to the step **416**. In the step **416**, the circuit **102** performs temporal filtering utilizing the remapped image data of the reference frame and the original data of the target frame.

The functions and structures illustrated in the diagrams of FIGS. **1-9** may be designed, modeled and/or simulated using one or more of a conventional general purpose processor, digital computer, microprocessor, microcontroller and/or similar computational machines, programmed according to the teachings of the present specification, as will be apparent to those skilled in the relevant art(s). Appropriate software, firmware, coding, routines, instructions, opcodes, microcode, and/or program modules may readily be prepared by skilled programmers based on the teachings of the present disclosure, as will also be apparent to those skilled in the relevant art(s). The software is generally embodied in a medium or several media, for example a non-transitory storage media, and may be executed by one or more of the processors. As used herein, the term "simultaneously" is meant to describe events that share some common time period but the term is not meant to be limited to events that begin at the same point in time, end at the same point in time, or have the same duration.

While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made without departing from the scope of the invention.

The invention claimed is:

1. An apparatus comprising:

an input circuit configured to receive a sequence of pictures; and

a processing circuit configured to (i) determine respective picture brightness values for a reference picture and a target picture selected from said sequence of pictures, (ii) remap image data of said reference picture based upon the respective picture brightness values, and (iii) perform temporal filtering between said reference picture and said target picture utilizing the remapped image data.

2. The apparatus according to claim **1**, wherein said processing circuit is configured to determine the respective picture brightness values using one or both of (i) actual measurements of picture brightness of said reference picture and said target picture and (ii) respective gain or gains applied to each of said reference picture and said target picture.

3. The apparatus according to claim **1**, wherein said processing circuit is configured to remap said image data based on at least one of (i) an average pixel value of each of said reference picture and said target picture, (ii) digital gains applied to each of said reference picture and said target picture, and (iii) analog gains applied to each of said reference picture and said target picture.

4. The apparatus according to claim **1**, wherein said processing circuit remaps said image data of whichever picture is darker than the other picture for use in motion detection and independently remaps said reference picture for use in said temporal filtering.

5. The apparatus according to claim **1**, wherein said processing circuit is further configured to remap said image data by:

determining a multiplier value based on one or more of (i) an actual measured picture brightness of each of said reference picture and said target picture, (ii) an average pixel value of each of said reference picture and said target picture, (iii) digital gains applied to each of said reference picture and said target picture, and (iv) analog gains applied to each of said reference picture and said target picture; and

multiplying the image data of at least said reference picture by said multiplier value.

6. The apparatus according to claim **1**, wherein said processing circuit is further configured to remap said image data using at least one of a one-dimensional lookup table and a multi-dimensional lookup table.

7. The apparatus according to claim **1**, wherein said processing circuit is further configured to perform at least one of gamma correction and color correction on said image data prior to remapping.

8. The apparatus according to claim **1**, wherein said processing circuit is further configured to perform motion detection by remapping said reference picture in a first mode, said target picture in a second mode, and selectively choosing between remapping said reference picture or remapping said target picture in a third mode.

9. The apparatus according to claim **8**, wherein in said third mode said processing circuit is configured to remap said image data based on actual measured picture brightness.

10. The apparatus according to claim **1**, further comprising a storage medium storing said sequence of pictures.

11. The apparatus according to claim **1**, wherein said apparatus is fabricated on one or more integrated circuits.

12. A method of performing temporal filtering comprising:

receiving a sequence of pictures;

determining a respective picture brightness for each of a reference picture and a target picture selected from said sequence of pictures;

remapping image data of said reference picture based upon the respective picture brightness; and

performing said temporal filtering between said reference picture and said target picture based upon the remapped image data.

13. The method according to claim **12**, wherein the respective picture brightness for each of the reference picture and the target picture is determined using one or both of (i) actual measurements of picture brightness of said reference picture and said target picture and (ii) respective gain or gains applied to each of said reference picture and said target picture.

14. The method according to claim **12**, wherein said image data is remapped based on at least one of (i) an average pixel value of each of said reference picture and said target picture, (ii) digital gains applied to each of said reference picture and said target picture, and (iii) analog gains applied to each of said reference picture and said target picture.

15. The method according to claim **12**, wherein said image data is remapped based upon whichever picture is darker than the other picture for use in motion detection and said reference picture is independently remapped for use in said temporal filtering.

16. The method according to claim **12**, wherein remapping said image data comprises:

determining a multiplier value based on one or more of (i) an actual measured picture brightness of each of said reference picture and said target picture, (ii) an average pixel value of each of said reference picture and said target picture, (iii) digital gains applied to each of said reference picture and said target picture, and (iv) analog gains applied to each of said reference picture and said target picture; and

multiplying the image data of at least said reference picture by said multiplier value.

17. The method according to claim **12**, wherein remapping said image data is performed using at least one of a one-dimensional lookup table and a multi-dimensional lookup table.

18. The method according to claim **12**, further comprising performing at least one of gamma correction and color correction on said image data prior to remapping the image data.

19. The method according to claim **12**, further comprising remapping said reference picture in a first motion detection processing mode, remapping said target picture in a second motion detection processing mode, and selectively choosing between remapping said reference picture or remapping said target picture in a third motion detection processing mode.

20. The method according to claim **19**, wherein said third motion detection processing mode is configured to remap said image data based upon actual measured picture brightness.

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